Review and Update

U.S. States and Territories National Tsunami Hazard Assessment: Historical Record and Sources for Waves

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U.S. DEPARTMENT OF COMMERCE
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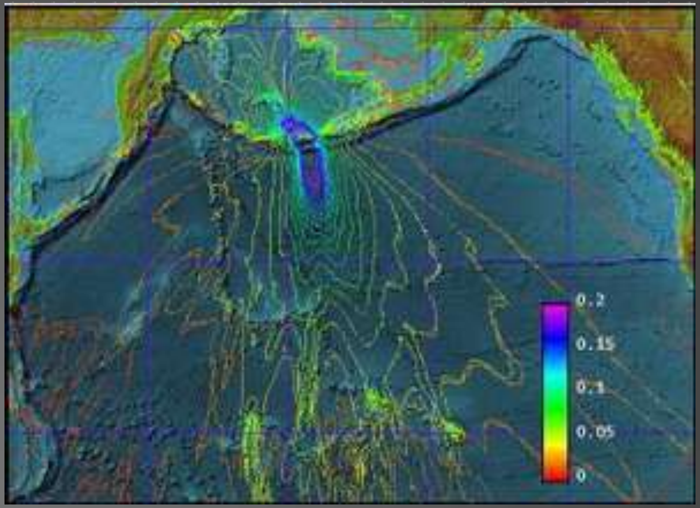
US TSUNAMI HAZARD ASSESSMENT

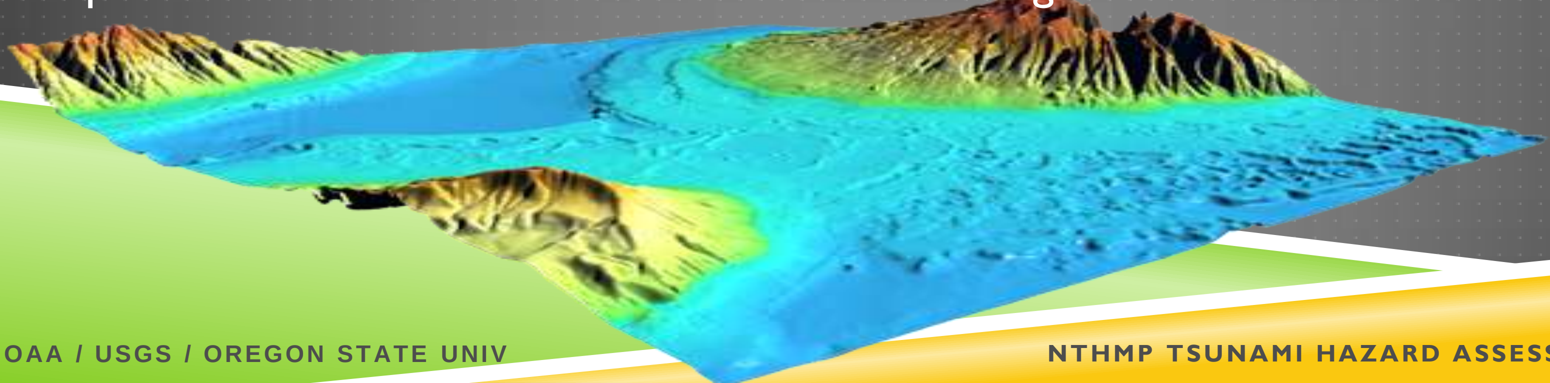
- Tsunami Risk Reduction for the United States: A Framework for Action, 2005, National Science and Technology Council
  - Develop tsunami hazard and risk assessments for all coastal regions of the US states and territories
- NOAA's National Geophysical Data Center (NGDC) and U.S. Geological Survey (USGS) collaborated on first Qualitative U.S. Tsunami Hazard Assessment, 2008
- National Academies Assessment of Tsunami Program, 2011
  - Initial national assessment of tsunami risk
  - Periodic assessment of the sources of tsunamis that threaten the U.S.
- NTHMP requested an update of the Tsunami Hazard Assessment, 2012
- Brief review of the 2008 assessment and progress to date

TSUNAMI HAZARD ASSESSMENT

- Probabilistic tsunami hazard analysis
  - Historical and Prehistorical (paleo) tsunami data
  - Quantitative probabilistic models of local and far-field tsunami sources (earthquake, landslide, volcano)
  - High-resolution DEMs (topography, bathymetry, tidal information)
  - Numerous inundation and propagation simulations for tsunami sources



- Goal of the ***first phase*** of the National Tsunami Hazard Assessment
  - Qualitative assessment of the hazard at the state level
- ***Second phase*** will update the qualitative assessment with new database searches and provide an overview of latest research in each region



TSUNAMI HAZARD ASSESSMENT

- Introduction
- Known Historical Tsunami Record
  - Information added on completeness of the record using tide gauge records
  - Database counts updated
  - Examine local vs distant tsunamis
- USGS Earthquake Hazards
- New section – Latest Research Results
- Gaps in Knowledge of Tsunami Sources
- Next Steps
- Conclusion
- Appendices

NINETEENTH CENTURY TIDE DATA

- Memory of most pre-1900 tide records has largely disappeared from the modern scientific literature…
- The only exceptions to this neglect are short segments of marigrams which have been used to reconstruct past tsunamis (e.g. ***Lander, et al., 1993, Tsunamis affecting the west coast of the United States, 1806–1992***, NGDC)
- Lander, et al., examined marigrams for all tsunami publications

  U.S. Tsunamis 1690-1988, Tsunamis Affecting Alaska 1737-1996; Caribbean Tsunamis 1498-1998, Tsunamis of the Eastern U.S. 1668-1992

US West Coast and Hawaii

Location	Start Date	Currently Digitized Hourly
San Francisco, CA	1853	1853-pr (present)
San Diego, CA	1853	1906-pr
Astoria, OR	1853	1925-pr
Port Townsend, WA	1855	1966, 1972-pr
Seattle, WA	1891	1899-pr
Kodiak, AK	1880	1975-pr
Honolulu, HI	1877	1877-82, 1905-pr

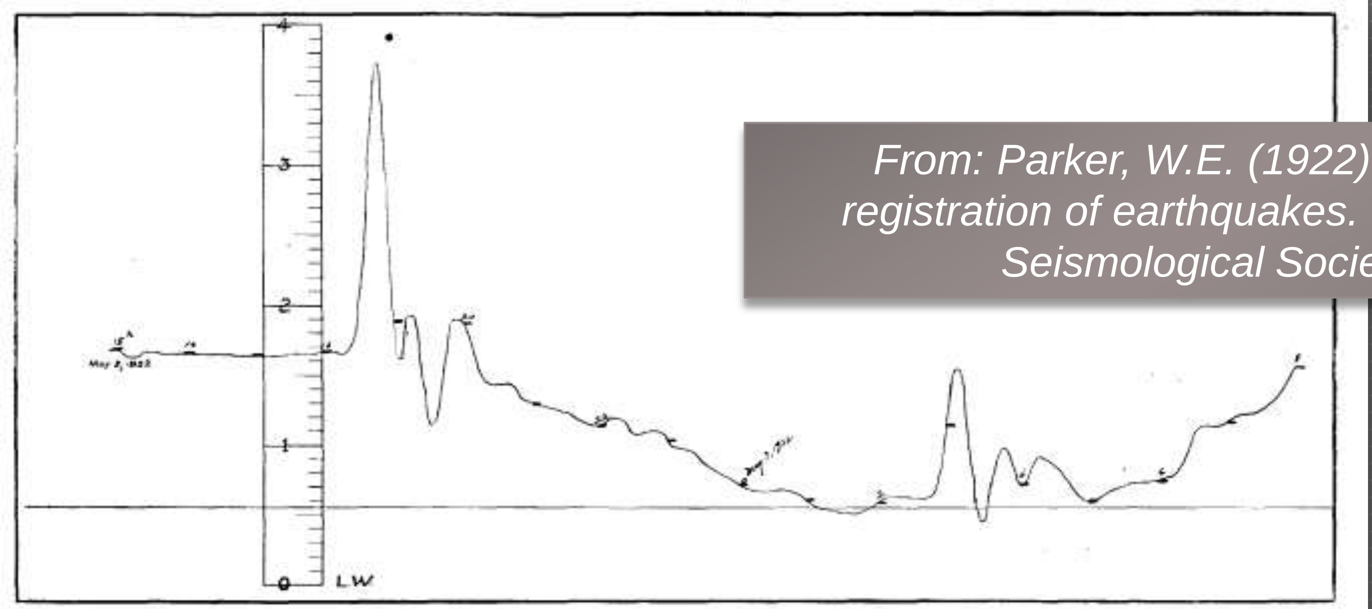
From: Talke and Jay (2013) Nineteenth Century North American and Pacific Tidal Data: Lost or Just Forgotten?

US East Coast

Location	Start Date	Hourly Data Available
Eastport, ME	1860	1930-pr
Portland, ME	1852	1912-pr
Boston, MA	1847	1921-pr
Newport, RI	1844	1930-pr
Willets Point, NY	1885	1957-2000
New York, NY	1844	1920-pr
Sandy Hook, NJ	1844	1910-pr
Baltimore, MD	1845	1902-pr
Annapolis, MD	1844	1928-pr
Washington, DC	1852	1931-pr
Old Point Comfort, VA	1844	1927-pr
Wilmington, NC	1882	1930-pr
Charleston, SC	1850	1921-pr
Fort Pulaski, GA	1851	1935-pr
Key West, FL	1847	1913-pr

UNUSUAL TIDAL REGISTRATION

- May 2, 1922 – unusual curve found on Galveston, TX tide gauge
- "These unusual waves are not of the nature caused by the tides or by meteorological conditions, but undoubtedly are of seismic origin."
- "It may be stated that it is now the practice of the Coast and Geodetic Survey to **examine the tide rolls whenever the seismograms indicate submarine earthquakes in the general region, and also to investigate the seismograms when tidal phenomena are unusual**.."



Tidal Registration, Galveston, Texas, May 2-3, 1922

From: Parker, W.E. (1922) Unusual tidal registration of earthquakes. Bulletin of the Seismological Society of America

EXAMINE THE HISTORICAL TSUNAMI RECORD

- Count tsunami events affecting each state
  - Bin tsunami events based maximum measured runup
    - 0.01 m ≤ runup ≤ 0.5 m
    - 0.5 m < runup ≤ 1.0 m
    - 1.0 m < runup ≤ 3.0 m, and
    - 3.0 m < runup
- Tsunami event could be counted in several states
  - 1952, 1960, 1964, etc.
- Provide dates of first tsunami observation and first tide gauge installation
  - **Record complete 1853-present (West coast), 1902-present (East coast)**
- Although not a vulnerability or risk assessment
  - Examine the severity of tsunamis by counting total number of deaths and dollar damage due to tsunamis in each state
  - Count tsunami events binned by local vs distant source

RESULTS – TSUNAMI EVENT RUNUPS BY STATE & REGION

- State tsunami events range from **none** in PA, DE, VA, NC, GA, AL, MS, and LA to **131** in Hawaii
- State tsunami events include both **local sources** of all types as well as runups resulting from a **distant source**
- Tsunami events:
  - **8% are in the Atlantic Basin** (Atlantic, Gulf, Puerto Rico, and the Virgin Islands)
  - **92% are in the Pacific** (US West Coast, Alaska, Hawaii, and western Pacific Islands)

Location (year of first confirmed report and tide gauge installation)	Total Events	Un-deter-mined	0.01 to 0.5	0.51 to 1.0	1.01 to 3.0	> 3.0	Total runups	Reported Deaths	$Million damage reported
Maine (1929, 1847)	1	1					3		
New Hampshire (1929, 1926)	1	1					1		
Massachusetts (1929, 1847)	1	1					2		
Rhode Island (1929, 1844)	2	1	1				3		
Connecticut (1964, 1932)	1	1					1		
New York (1895, 1844)	2	1	1				7		
New Jersey (1918, 1844)	6	3	2	1			8		
Pennsylvania (, 1981)									
Delaware (, 1896)									
Maryland (1929, 1844)	1		1				1		
Virginia (, 1844)									
North Carolina (, 1882)									
South Carolina (1886, 1850)	2	1	1				2		
Georgia (, 1851)									
Florida (1886, 1898)	4	3	1				5		
Atlantic Coast Totals	**21**	**13**	**7**	**1**	**0**	**0**	**33**	**0**	**$0**
Florida (, 1847)									
Alabama (, 1966)									
Mississippi (, 1978)									
Louisiana (, 1932)									
Texas (1918, 1908)	1	1					1		
Gulf Coast Totals	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**$0**
Puerto Rico (1867, 1954)	10	2	3	2	1	2	36	140	$4
Virgin Islands (1690, 1975)	9	2	3	1	1	2	22	24	
PR & VI Totals	**19**	**4**	**6**	**3**	**2**	**4**	**58**	**164**	**$4**
Washington (1891, 1855)	28	2	20	2	3	1	98	1	$2
Oregon (1854, 1853)	29		23	1	3	2	98	5	$1
California (1812, 1853)	87	5	60	8	10	4	614	19	$79
West Coast Totals	**144**	**7**	**103**	**11**	**16**	**7**	**810**	**25**	**$82**
Guam (1849, 1948)	16	3	10		2	1	25	1	
Northern Mariana (1990, 2000)	11	1	9		1		12		
American Samoa (1837, 1948)	67	10	48	5	3	1	294	34	**$125**
Pacific Is. Totals	**94**	**14**	**67**	**5**	**6**	**2**	**331**	**35**	**$125**
Alaska (1737, 1872) Totals	**97**	**7**	**63**	**5**	**6**	**16**	**461**	**222**	**$122**
Hawaii (1812, 1872) Totals	**131**	**2**	**94**	**5**	**12**	**18**	**1713**	**293**	**$90**
AMERICAN Totals	**507**	**48**	**340**	**30**	**42**	**47**	**3407**	**739**	**$423**

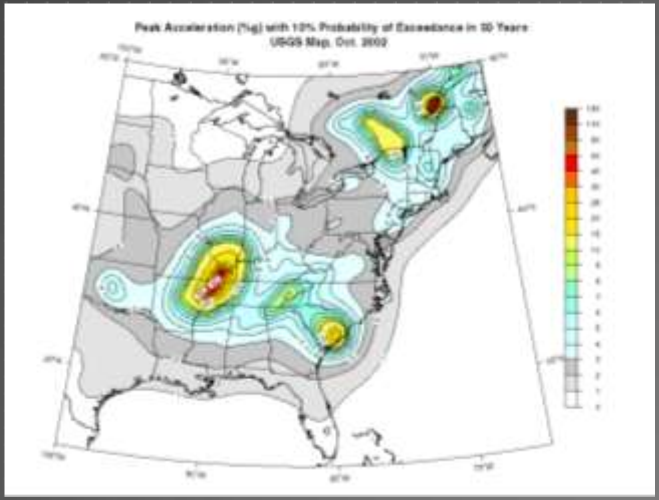
RESULTS – TSUNAMI EVENT LOCAL / DISTANT RUNUPS BY STATE AND REGION

- Hawaii & US West Coast States – Distant caused more deaths & $damage
- Alaska, Caribbean & Pacific Is territories - Local caused all deaths & $damage
- 95% of U.S. deaths **before** TWCs; 60% of damage **since** TWCs
- All deaths resulted from runups **>3m**, except one in CA 2011 (only death: Japan source)

	Local	Distant	Local	Distant	Local	Distant	Local	Distant	Local	Distant	Local	Distant	Local	Distant
	Undetermined		0.01 to 0.5 m		0.51 to 1.0 m		1.01 to 3.0		>3.0 m		**Deaths***		**$Million damage**	
Rhode Island		1		1										
New York	1		1											
New Jersey	1	2		2										
Maryland				1										
South Carolina	1			1										
Florida	1	2		1		1								
Atlantic Coast Totals	4	**5**	1	**6**		**1**								
Puerto Rico	2		1	2	2		1		2		140			
Virgin Islands	1	1	1	2	1		1		2		24			
PR & VI Totals	3	**1**	2	**4**	3		2		4		164		$4	
Washington	2			20		2	2	1		1	1			$2
Oregon			1	22		1		3	1	1		5		$1
California	5		5	55	3	5	2	8	3	1	2	17		$79
West Coast Totals	7		6	**97**	3	**8**	4	**12**	4	**3**	3	**22**		**$82**
Guam	2	1		10			2		1		1			
N. Mariana	1		2	7				1						
American Samoa		10	8	40		5	1	2	1		34		$125	
Pacific Is. Totals	3	**11**	10	**57**		**5**	3	**3**	2		35		$125	
Alaska Totals	7		20	**43**	4	**1**	1	**5**	15	**1**	222		$122	
Hawaii Totals	1	1	2	**92**		**5**	2	**10**	4	**14**	49	**244**	$1.5	**$88.5**
AMERICAN Totals	25	**18**	41	**299**	10	**20**	12	**30**	29	**18**	473	**266**	$252.5	**$170.5**

USGS EARTHQUAKE HAZARDS ASSESSMENT

Earthquake databases can be used to extend the historical tsunami record backward in time. ***Do these searches need to be re-run?***



Non-Subduction zones

State/Territory	Earthquake with Mag > 6.5 in 500 years within 50 km of coast	Earthquake with Mag > 6.5 in 5000 years within 50 km of coast	Historical maximum magnitude observed nearshore or offshore	Comment
U.S. Atlantic Coast				
Maine	<3%	<30%	<6	
New Hampshire	<3%	<30%	<6	
Massachusetts	<3%	<25%	<6	
Rhode Island	<2%	<15%	<6	
Connecticut	<2%	<30%	<6	
New York	<4%	<30%	<6	
New Jersey	<4%	<30%	<6	
Pennsylvania	<3%	<15%	<6	
Delaware	<3%	<15%	<6	
Maryland	<2%	<15%	<6	
Virginia	<1%	<4%	<6	
North Carolina	<1 to 5%	<5%	<6	
South Carolina	<35%	100%	7.3	1886 Charleston, non-destructive tsunami
Georgia	<1%	<10%	<6	
Florida	<1%	<3%	<6	
U.S. Gulf Coast				
Florida	<1%	<3%	<6	
Alabama	<1%	<4%	<6	
Mississippi	<1%	<5%	<6	
Louisiana	<1%	<5%	<6	
Texas	<1%	<4%	<6	

Subduction zones

State/Territory	Non-subduction earthquake with mag > 6.5 in 500 years within 50 km of coast	Subduction zone event with mag >msubduct in 500 years within 150 km of coast	Maximum magnitude observed or estimated for nearshore or offshore	Comment
Puerto Rico and the Virgin Islands, msubduct = 7.5				
Puerto Rico	100%	~100%	7.5	1918 Mona Passage, severe tsunami**
Virgin Islands	100%	~100%	7.5	1867 Virgin Islands, severe tsunami
Pacific Coast--Cascadia, msubduct = 8.1				
Washington	30% to 90%	~100%	9+	1700 Cascadia, severe tsunami
Oregon	10% to 100%	~100%	9+	1700 Cascadia, severe tsunami
California	100%	~100%	9+	1700 Cascadia, severe tsunami
Pacific Coast--Alaska, msubduct = 7.5				
Alaska	100%*	~100%	9.2	1964 Alaska, severe tsunami
Western Pacific, msubduct = 7.8				
Guam	N/A	~100%	7.8	1993 Guam, non-destructive tsunami
Northern Mariana	N/A	~100%	7.8	1993 Guam, non-destructive tsunami
American Samoa	N/A	~100%	8.5	1917 Northern Tonga trench, moderate tsunami

Alaska calculation for mag>6.5 includes subduction interface events
*Events as large as magnitude ~8 are estimated in the Puerto Rico trench

Hawaii, Southern California, and Arctic Coast of Alaska

State/area	Mag > 6.5 in 500 years within 50 km of coast	Mag > 7.5 in 500 years within 50 km of coast	Maximum magnitude observed or estimated for nearshore or offshore	Comment
Hawaii and Southern California				
Hawaii	~100%	~100%	7.9	1868 Ka'u district, severe tsunami
Southern California	~100%	~100%	7.1	1927 Lompoc, moderate tsunami
Arctic Coast—Alaska				
Alaska	<1%	N/A	<6	Arctic coast rated no tsunami risk by Alaska

QUALITATIVE TSUNAMI HAZARD ASSESSMENT

Table A. Qualitative tsunami hazard assessment based on NGDC and USGS databases.

Region	*Hazard based on runups*	*Hazard based on frequency*
U.S. Atlantic coast	Very low to low	Very low
U.S. Gulf coast	Very low	Very low
Puerto Rico and the Virgin Islands	High	High
U.S. west coast	High	High
Alaska	Very high	Very high
Hawaii	Very high	Very high
U.S. Pacific island territories	Moderate	High

Table A. Qualitative tsunami hazard assessment based on NGDC and USGS databases.

Region	*Hazard based on runups*	*Hazard based on frequency*	*Hazard based on local earthquakes*	*Number of reported deaths*
U.S. Atlantic coast	Very low to low	Very low	Very low to low	None
U.S. Gulf coast	Very low	Very low	Very low	None
Puerto Rico and the Virgin Islands	High	High	High	164
U.S. west coast	High	High	High	25
Alaska	Very high	Very high	High	222
Hawaii	Very high	Very high	High	293
U.S. Pacific island territories	High	High	High	35

Suggested 2013

LATEST RESEARCH (JUST A FEW HIGHLIGHTS)

- ten Brink, U., Chaytor, Geist, Brothers, Andrews (in press) Tsunami hazard assessment for the U.S. Atlantic margin: Progress Procedures, and Processes
  - "Tsunamis along the U.S. Atlantic margin are rare events, because potential earthquake-generated tsunamis are located in areas of slow tectonic activity, and because landslide-generated tsunamis are probably triggered by infrequent earthquakes along the margin."
- Goldfinger, Nelson, Morey, et al. (2012) Turbidite event history—Methods and implications for Holocene paleoseismicity of the Cascadia subduction zone: *USGS Professional Paper 1661–F*
- Goldfinger, Morey, Black, Beeson, Nelson, and Patton, (2013) Spatially limited mud turbidites on the Cascadia margin:
- segmented earthquake ruptures?: *Nat. Hazards Earth Syst. Sci., 13, 1–38, 2013*
  - **"The sequence of 41 events defines an average recurrence period for the southern Cascadia margin of ~240 years during the past 10 k.y. "**
  - **Updated in 2013 paper, southern recurrence rate revised to 195 years post 4800 yrs.**
- Frankel (2011) Summary of Nov 2010 Meeting to Evaluate Turbidite Data for Constraining the Recurrence Parameters of Great Cascadia Earthquakes for the Update of National Seismic Hazard Maps, USGS OF 2011–1310
  - **"Participants were comfortable with the 500-600 yr average recurrence time for long ruptures of the entire CSZ accomplished either by M9 or serial M8 earthquakes. "**
  - **Southern rate compromise made at ~ 340 year recurrence period.**
- Shennan, Bruhn, Plafker (2009) Multi-segment earthquakes and tsunami potential of the Aleutian megathrust, *Quaternary Science Reviews*, v. 28
  - **"We present evidence that earthquakes 900 and 1500 years ago simultaneously ruptured adjacent segments of the Aleutian megathrust and the Yakutat microplate, with a combined area 15% greater than 1964, giving an earthquake of greater magnitude and increased tsunamigenic potential."**

LATEST RESEARCH - CONTD

- Priest, Goldfinger, Wang, Witter, Zhang, Baptista (2009) Confidence limits for tsunami-inundation limits in northern Oregon inferred from a 10,000-year history of great earthquakes at the Cascadia subduction zone, *Natural Hazards* tsunami scenarios tested against local runups, and subsidence evidence
- Burak, Eble, Titov, Bernard (2010) Tsunami Hazard Assessment Special Series: Vol. 2 Distant tsunami threats to the ports of Los Angeles and Long Beach, California
- Thio, Somerville, Polet (2010) Probabilistic tsunami hazard in California, Pacific Earthquake Engineering Research Center Report 2010/108
- Rabinovich, Thomson, Titov, Stephenson, Rogers (2008) Locally Generated Tsunamis Recorded on the Coast of British Columbia. *Atmosphere-Ocean*, v. 46
  - "Contrary to accepted understanding, our findings demonstrate that local earthquakes with magnitudes far below the generally accepted threshold level of 7.0 are capable of generating significant tsunamis."

LATEST RESEARCH - CONTD

- Lay, Ammon, Kanamori, Rivera et al (2010) The 2009 Samoa–Tonga great earthquake triggered doublet *Nature, 466, 964-968*
  - "within two minutes of the initiation of a normal faulting event with moment magnitude 8.1 in the outer trench-slope …, two major interplate underthrusting subevents (M= 7.8), …tsunami about 12 metres run-up that claimed 192 lives in Samoa, American Samoa and Tonga"
- Yamazaki, Cheung, Pawlak, and Lay et al (2012) Surges along the Honolulu coast from the 2011 Tohoku tsunami *GRL, 39,* L09604
  - "A nearshore observatory in Honolulu recorded clear signals of the surface elevation and flow velocity at 12 m water depth, where adjacent harbors and marinas experienced persistent hazardous surges."
- Lay, Ye, Kanamori, et al., (2013) The October 28, 2012 M_w 7.8 Haida Gwaii underthrusting earthquake and tsunami: *Slip partitioning along the Queen Charlotte Fault transpressional plate boundary EPSL, 375, 57-70.*
  - "The shallow thrusting caused seafloor uplift that generated substantial localized tsunami run-up and a modest far-field tsunami that spread across the northern Pacific, prompting a tsunami warning, beach closure, and coastal evacuation in Hawaii"

- Questions?